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RETORT BRAZE BONDING OF BORSIC/ALUMINUM COMPOSITE SHEET TO TITANIUM

By B. A. Webb
J. F. Dolowy, Jr.

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RETORT BRAZE BONDING OF BORSIC/ALUMINUM COMPOSITE SHEET TO TITANIUM

B. A. Webb
J. F. Dolowy, Jr.
DWA Composite Specialties, Inc.

SUMMARY

Braze bonding studies between BSC/Al composite and titanium were conducted to establish acceptable brazing techniques and to assess potential joint efficiencies. Approximately 75 overlap tensile specimens and 20 honeycomb sandwich specimens were fabricated for delivery to NASA. Excellent braze joints were produced which exhibited joint strengths exceeding 117 MPa (17,000 psi) and retained up to 2/3 of this strength at 589K (600°F). Problems were encountered with consistency of results which were attributed to brazing technique variations. These were minimized late in the program. The major problem, which has yet to be overcome is the prevalence of excessive composite degradation as a result of the thermal and/or braze diffusion effects encountered during the braze cycle. This is due to the high temperature [> 855K (1080°F)] required to achieve a satisfactory braze joint. Aluminum diffusion barriers of either 6061 or 1100 Al foil bonded to the composite surface did not have a noticeable effect on composite degradation although this requires more detailed study. In addition, it was found that leached fiber testing was not a reliable measure of BSC/Al composite degradation and the BSC fiber degradation mechanism is somewhat different from uncoated boron.

It is evident from this work that the degradation problem and potential solutions demand immediate and intensive study if brazing is to be utilized as an efficient joining technique.

INTRODUCTION

Effective utilization of metal-matrix composites in high performance structures can be significantly enhanced through the use of braze bonding as a method of secondary fabrication. However, brazing as an economical and reliable joining process, has yet to be successfully applied to boron or Borsic reinforced aluminum composites to any appreciable degree. To date, a great deal of experience and data have been accumulated on metallurgical joining of metal-matrix composites by techniques such as spot welding, seam welding, electron beam welding, diffusion bonding, etc., but brazing efforts have been somewhat less productive. This is primarily due to the deleterious effects standard brazing conditions have on resultant composite mechanical properties.

The objective of this study was to investigate retort brazing techniques for achieving sound joints between BSC/Al composite and titanium and to determine the load carrying capability of such joints. The study included evaluation of braze alloys and diffusion barriers as well as effects of the brazing cycle on composite behavior. Samples of overlap tensile and honeycomb sandwich brazed joints were delivered to NASA for evaluation.

PROCEDURES

Materials

All of the composite material used in this study consisted of diffusion bonded 9 layer Borsic/aluminum composite plate except for initial trial runs which utilized four (4) layer composite. The baseline material was the standard .14 mm (.0057 in.) Borsic/6061 aluminum matrix material. To evaluate possible advantages of diffusion barriers, standard composite plate was also made up with thicker .089 mm (.0035 in.) 6061 aluminum surface foils and .076 mm (0.003 in.) thick commercially pure titanium cover foils.

Two aluminum alloy braze foils, 713 and 718, were used in this study. The 713 braze foil was .025 mm (0.001 in.) thick and was used both as an interleaf in the braze joint and also integrally bonded to the composite surface. The 718 braze foil was .127 mm (0.005 in.) thick and was used primarily as an interleaf and not diffusion bonded to the composite plate.

The titanium used in this study was 1.27 mm (0.050 in.) thick Ti-6 Al-4V sheet stock supplied by NASA, Langley, in 5 cm x 20 cm (2 in. x 8 in.) strips or 20 cm x 20 cm (8 in. x 8 in.) sheet.

Specimens

Retort brazing techniques for three overlap tensile type specimens and one honeycomb-core type specimen were investigated. The configuration for a single overlap tensile specimen is shown in Fig. 1. Two double overlap tensile configurations (Types I and II) are shown in Figs. 2 and 3. The Type II double overlap configuration consisted of two titanium plates joined by two 25.4 mm (1.0 in.) wide composite

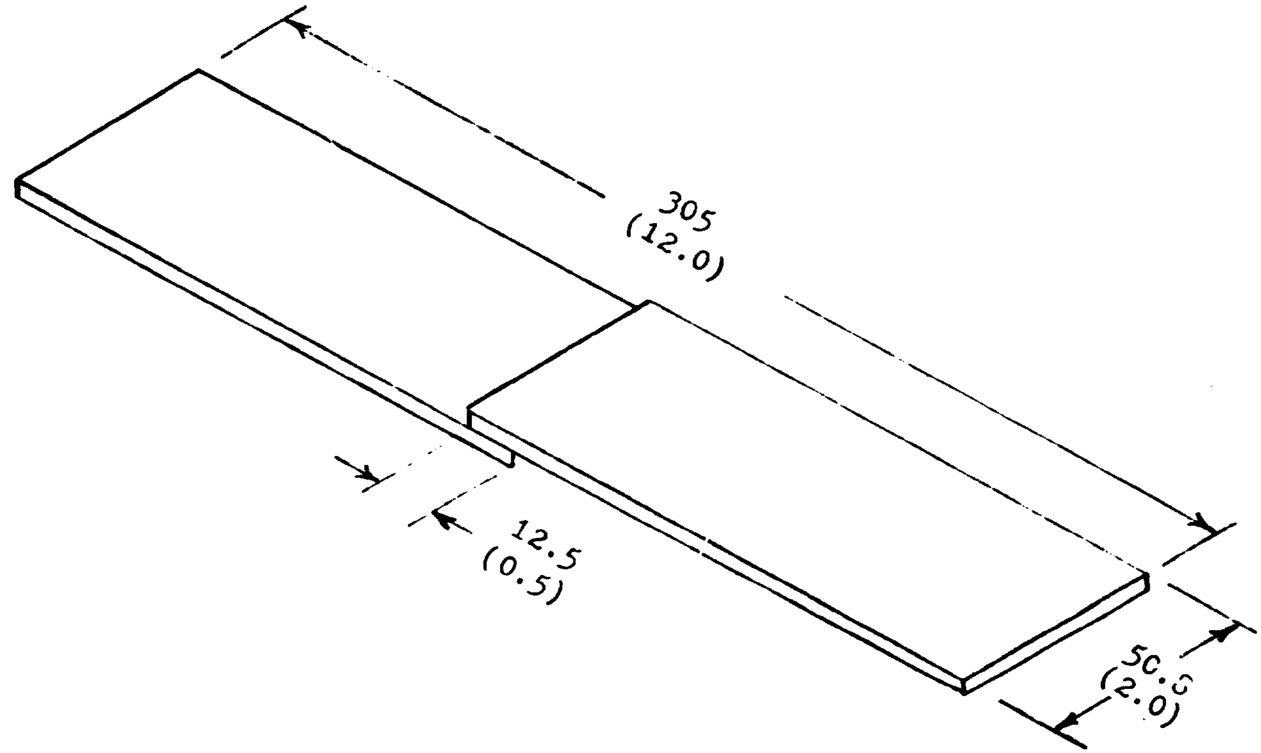


Figure 1. SINGLE OVERLAP TENSILE SPECIMEN CONFIGURATION

All Dimensions in mm (inches).

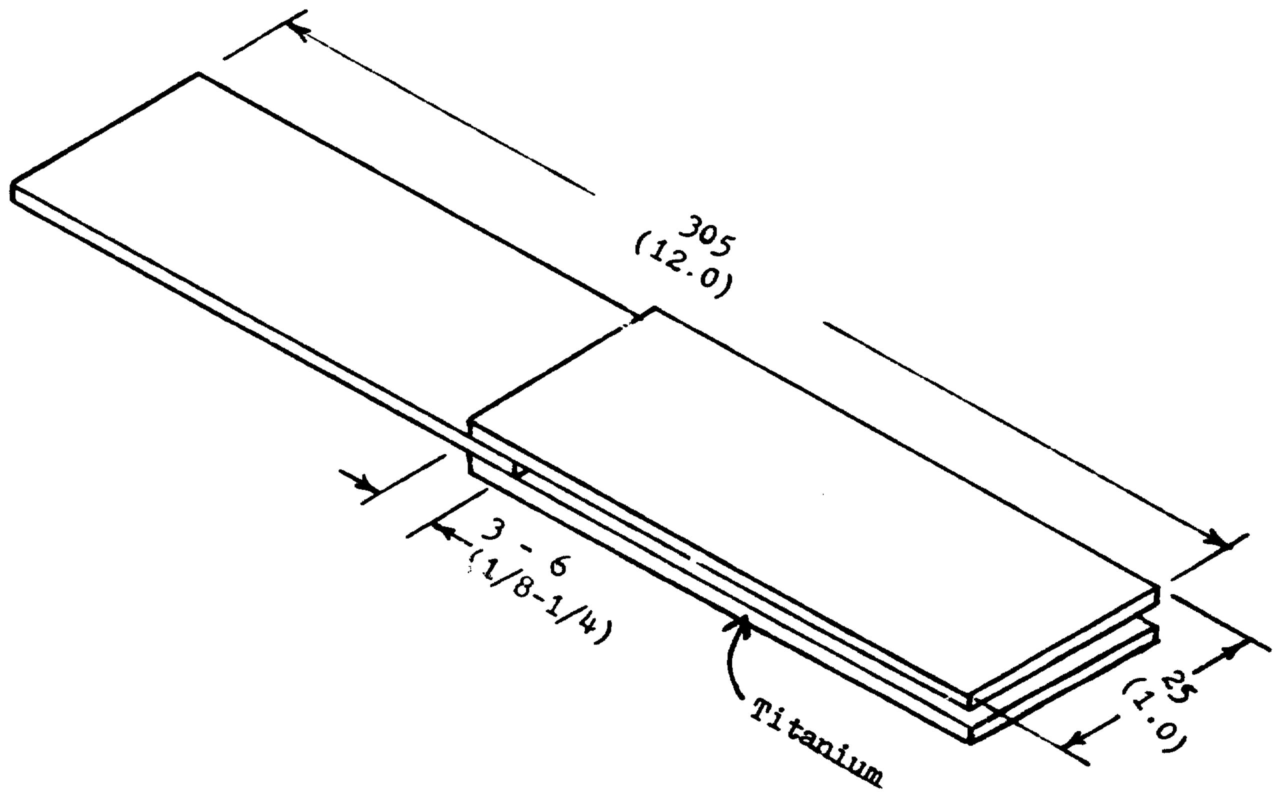
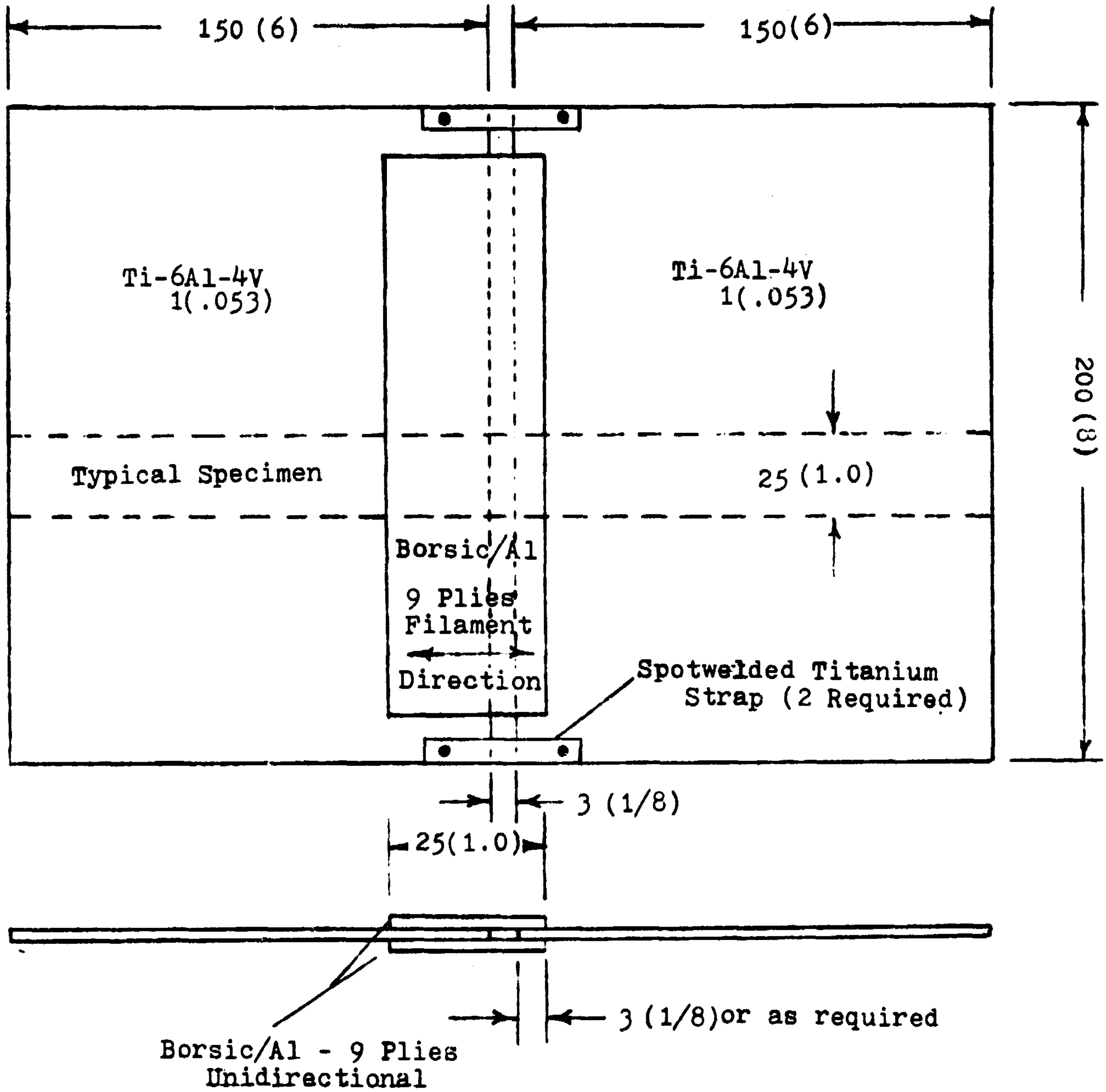


Figure 2. DOUBLE OVERLAP TENSILE SPECIMEN CONFIGURATION (TYPE I)

All dimensions in mm (inches).



NOTE: From each plate 7 specimens 25(1.0) inch wide can be machines as shown.

Figure 3. DOUBLE OVERLAP TENSILE SPECIMEN CONFIGURATION (TYPE II)

All dimensions in mm (inches)

strips (Fig. 3). This configuration utilized far less composite material. The honeycomb core sandwich test configuration is shown in Fig. 4. This configuration used a 25.4 mm (1 in.) deep titanium honeycomb core and two .16 cm (.063 in.) thick, (9 ply) uniaxial Borsic/aluminum composite face sheets.

Brazing Processes

All brazing runs were conducted in seam welded stainless steel retorts using roughing pump vacuum levels measured with a standard NRC thermocouple vacuum gage. Temperature measurements were made in ^{o}F using chromel-alumel thermocouples and a temperature indicator up to 1366K (2000^{o}F). Brazing cycles were run in a resistance heated furnace.

The primary brazing parameters evaluated were time and temperature, and to a lesser extent, pressure. In addition, vacuum level was evaluated to determine the range of permissable vacuum levels which could be tolerated and still achieve sound joints. Temperatures ranged from the lowest melting temperature of the brazes 850K (1070^{o}F) up to a high of 883K (1130^{o}F) in 5K (10^{o}F) increments. Time at temperature was varied from 5 minutes to 30 minutes in 5 minute increments. In addition, the time to reach the desired braze temperature from 833K (1040^{o}F) (below which thermal degradation is not a factor) was evaluated to account for the total thermal energy to which the composite was subjected. Most braze cycles were run at a one atmosphere pressure applied at the joint, but selected runs were made at less than atmospheric pressure by varying the specimen jigging technique.

In the process of evaluating effects of pressure on joint quality, it was noted that excessive braze expulsion often occurred in joints brazed at one atmosphere pressure. To counter this trend several specimens were fabricated with a .075 mm (.003 in.) diameter fiber across the joint area

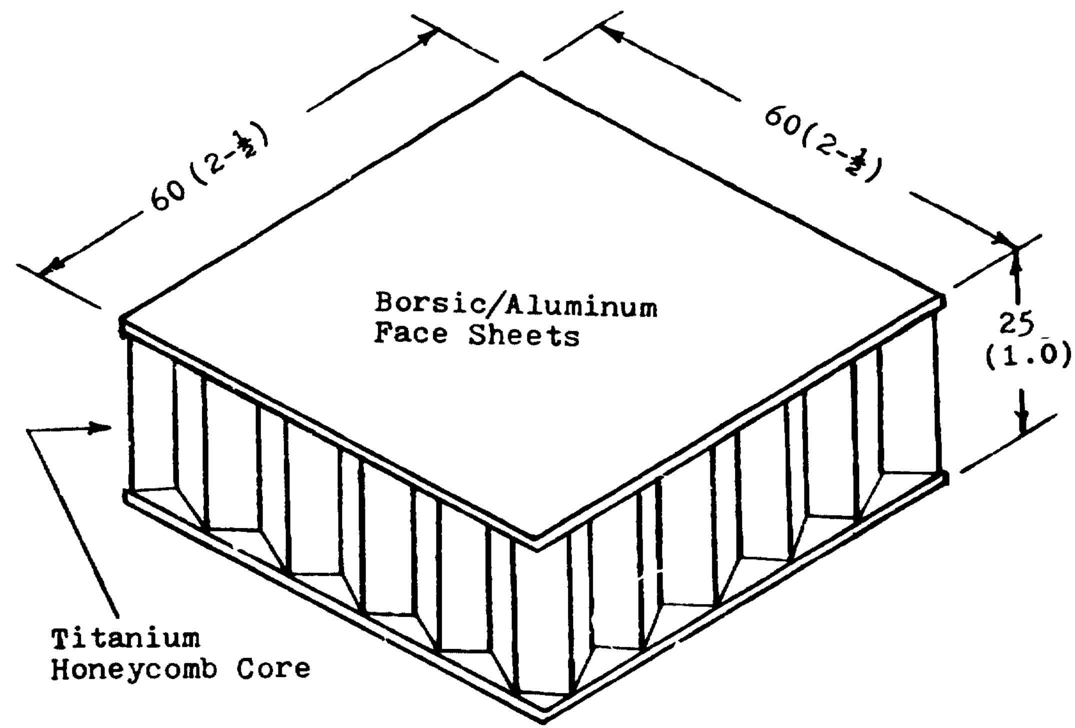


Figure 4. BRAZED HONEYCOMB CORE SPECIMEN CONFIGURATION
All Dimensions in mm (inches).

with the braze foil. It was felt this would guarantee a joint thickness of approximately .025 mm (.001 in.) (since the soft surface of the BSC/Al piece would allow the fiber to indent itself). This technique did work and gave several moderately strong joints, however it impeded braze flow and caused no end of problems in precisely positioning of these fibers in the joint areas.

Tests

As fabricated composite plates were tensile tested and the break surfaces examined to insure that the material was well bonded and fibers were not degraded. In addition, fibers were leached from the composite and compared to virgin fibers by bend testing. Composite samples were then run through typical braze cycles with and without braze in contact with the composite surface. Fibers were leached from these samples and bend tested to evaluate the effects of temperature and braze diffusion on fiber degradation.

Selected overlap tensile specimens were tested to determine joint integrity and establish the most satisfactory techniques for fabricating braze bonded specimens for delivery to NASA, Langley for evaluation of joint strength as a function of temperature. The failed specimens were examined to evaluate the degree of bonding achieved and the nature of the failures, and to determine improvements necessary in the jigging and/or bonding procedure. In addition, the brazed specimens were evaluated for joint cleanliness, braze flow, wetting, and joint uniformity.

The honeycomb core sandwich test plates were evaluated by peeling the BSC/aluminum face sheets off the core. The appearance of the braze side of the face sheet and the fillet appearance of the exposed core were used to choose braze parameters for honeycomb core sandwich plates to be delivered to NASA, Langley. The specimens were precisely

tested in face sheet tension by adhesive bonding grip plates onto each face sheet and pulling in a standard tensile machine. The failed specimens were evaluated for degree of brazing/wetting achieved, the failure mode, appearance of the failed joint, and any indications of overheating.

RESULTS

Composite And Fiber Evaluation

The as fabricated BSC/aluminum composite material used contained approximately 45% Borsic fiber with typical composite tensile strengths ranging from 1170 - 1380 MPa (170-200 ksi). This range is consistent with the v/o loading and strength of the Borsic fiber used. Fibers leached from these composite plates were compared with virgin fiber via bend tests and no measurable degradation could be found since the differences in bend test results were negligible - i. e. 15% breaks at 3700 MPa (540 ksi) bend stress and none at 3000 MPa (430 ksi) bend stress.

Fiber bend tests were also conducted on fibers leached from composites exposed to temperature cycles ranging from a low of 850 K (1070°F) to a high of 878 K (1120°F) for 5 - 10 minutes. In this case, the thermal treatments appeared to have negligible effect on the ability of the fibers to withstand the 3000 MPa (430 ksi) bend stress, but with increasing time and temperature the ability to withstand 3700 MPa (540 ksi) bend test was markedly reduced. Additional thermal tests run on specimens with molten braze contact showed the same trend, however, degradation of the fiber strength at the 3000 MPa (430 ksi) bend stress level became somewhat more pronounced, <u>but still not excessive</u>.

Finally, fibers leached from brazed specimens also showed very negligible degradation at the 3000 MPa (430 ksi) level but significant degradation at the 3700 MPa (540 ksi) bend stress level. These results tend to indicate that for leached fibers, the strength seems to normalize at a level somewhat above 3000 MPa (430 ksi) bend stress but higher strength fibers tend to degrade to the lower plateau. Table I summarizes leached fiber tests.

TABLE I

LEACHED FIBER BEND TEST DATA

FIBER CONDITION	EXPOSURE CONDITIONS Temp. °K	(°F)	Time (Min.)	FIBER BREAKS/TOTAL TESTS 3000MPa (430ksi)	3200MPa (460ksi)	3700MPa (540ksi)
BSC/Al, with 3.5 mil 6061 diff. barrier; no braze	855	(1080)	20	3/15		10/10
BSC/Al, with 3.5 mil 6061 diff. barrier; 713 braze	872	(1110)	5	1/40*		8/10
	872	(1110)	5	1/58*	1/54*	
	858	(1085)	10	0/20		6/8
	855	(1080)	10	1/70*	1/70*	
BSC/Al, with 5.0 mil 1100 diff. barrier; no braze	872	(1110)	5	7/40		18/20
	872	(1110)	5	0/29	2/36	
BSC/Al, with 5.0 mil 1100 diff. barrier; 713 braze	858	(1085)	10	2/25		7/10
	855	(1080)	20	4/40		10/10
	855	(1080)	10	2/57*	7/34*	

* Some fibers were tested from areas outside of braze contact area.

In fabricating the BSC/Al composite materials used in these specimens, wide variations were noted in the as received fiber. In particular, intermittent sections would exhibit brittle spots where the slightest flexural force on the fiber would break it. Often these areas could be felt by running the fiber carefully between two fingers, this indicates a surface flaw phenomena may have caused the problem.

The observations that exposure to braze temperatures would reduce the composite strength was initially confusing, and led to repeated checkout and calibration runs for all platens, T/C, and read out equipment. The review, late in this program, of reference 1 on metal-matrix interfaces helped explain the reaction and degradation phenomena taking place. In an over simplified model; irregularities or thin spots in the SiC coating allow hot aluminum (especially if incipient wetting can take place in the matrix) to contact the boron and react forming $Al\ B_2$. This reaction product forms a brittle, yet effective couple between the matrix and the fiber at the interface, which allows a crack to start and propogate through the fiber when in the composite, yet upon NaOH leaching of the fibers for test, very little strength degradation could be noted. The reference report also noted that upon chemical removal of the matrix, the aluminum rich areas in the interface zone are also leached leaving a honeycomb type hollow/brittle structure surrounding the reacted areas on the BSC fiber - but now this interface is friable and not capable of propogating cracks into the boron, and consequently the boron appears strong again.

Overlap Tensile Specimens

Single Overlap - The single overlap tensile specimens were brazed at temperatures ranging from 850/855 K (1070/1080°F) for 20 minutes to 872 K (1110°F) for 5 minutes and

all but the very lowest temperatures gave good appearing joints. However, joint uniformity and alignment were erratic due to the jigging procedure used. Consequently, joint strengths were generally poor. Initially the jigging technique used consisted of a simple stack up of the constituent parts. Then a stop-off (cover sheet) was placed between the stack and the vacuum retort. When less than one atmosphere vacuum pressure was desired on the specimen, steel shims were added to the stack to react the load created by the retort. A second set of single overlap tensile specimens was fabricated using an improved jigging technique and resulted in much improved braze joints, however, sporadic vacuum problems were evident. Brazed joint strength ranged from 27.6 to 69 MPa (4 to 10 ksi). All failures were in the brazed joint and revealed non-uniform wetting due to both alignment and oxidation.

<u>Double Overlap Type I</u> - The double overlap type I (Fig. 2) specimens were 2.54 cm (1") wide with .32 cm - .64 cm (1/8" - ¼") joint length. Results with these specimens were generally much improved and more consistent than the single overlap specimens with failure stresses falling in the 52-59 MPa (7.5-8.5 ksi) range with a high of 86 MPa (12.4 ksi). However, in every case complete joint area bonding was not achieved due to faulty jigging. In many cases the joint strength locally exceeded the interlaminar shear strength of the composite resulting in composite surface layer shear out. Table II summarizes the data for this series of braze trials.

Additional braze trials on the 2.54 cm (1") wide double overlap type I configuration continued to give similar but erratic results due to minor jigging problems, but improvements were noted due to improved vacuum level, use of titanium foil surrounding the joint to getter oxygen, and better jigging. A final series of braze trials was run using a 861/866 K (1090/1100^{o}F) braze cycle of 10 minutes

TABLE II

TENSILE STRENGTH DATA FROM DOUBLE OVERLAP SPECIMENS - TYPE 1

(Room Temperature Tests)

BRAZE CYCLE Temp. °K	(°F)	Time (Min.)	SHEAR STRESS MPa	(ksi)	COMMENTS
855	(1080)	10	51 to 53	(7.4 - 7.7)	Uneven wetting
855/861	(1080/90)	16	52 to 58	(7.5 - 8.3)	Uneven wetting
861/864	(1090/95)	7	70 T	(10.2)	Minor discoloration Minor non-wetting
861/864	(1090/95)	7	70 T	(10.2)	Brazed one surface only
861/866	(1090/1100)	12	55	(7.9)	
861/866	(1090/1100)	10	84 T	(12.2)	
866/877	(1100/20)	8	52	(7.5)	
861	(1090)	20	No joint		Larger retort used, no braze flow occurred
858/864	(1085/95)	60	48 to 86*	(7.0 - 12.4)	Jig slipped, larger retort slowed heat up rate

T Titanium getter foil used in braze retort

* Braze joint was only .08 long because of jig slippage.

under vacuum pressure. All samples came out clean and free of oxidation. The test results are summarized in Table II. Of interest is the appearance of failure ocurring in the composite rather than the joint for one specimen at a stress of 86 MPa (12.4 ksi) which translates to a failure stress of 828 MPa (120,000 psi) in the composite indicating degradation. Although these specimens were not completely wetted over the entire braze joint area, the data demonstrates that efficient braze joints are achieved when good, uniform contact is maintained during the braze cycle.

Double Overlap Type II - Brazing experiments on the type II double overlap tensile specimens required several modifications to the jigging procedure and also created new problems in maintaining flatness, minimizing oxidation, and changing heat-up rates due to increased mass. Consequently, numerous braze runs were made to solve these problems.

Overall, jigging was the overriding problem because the uniformity of the braze joint was highly sensitive to uniformity of joint contact and contact pressure. Consequently, pressures less than 1 atmosphere were soon discarded as inadequate to maintain reasonable flatness. Once the jigging procedure was adequate, atmosphere control, heat-up rate, and bonding temperature could be evaluated more realistically.

Several plates of the type II configuration were run through braze cycles at temperatures ranging from 850 to 883 K (1070°F to 1130°F) to establish acceptable heating cycles, jigging modification, and atmosphere control. Following evaluation of these plates, a series of plates were brazed and delivered to NASA for evaluation. These plates were cut into strips to yield 2.54 cm (1") wide double overlap tensile specimens as shown in Fig. 3 previously. Tensile testing was conducted at room temperature, 422 K (300°F), 505 K (450°F) and 589 K (600°F). Brazing

parameters and test results are presented in Table III.

It is evident that the wide variability in the data is more easily related to problems in braze joint uniformity, premature composite failure, and joint contamination rather than brazing parameters, except in the case where the temperature used is too low to get complete braze flow.

Honeycomb Core Sandwich Specimens

Honeycomb core sandwich specimens having 15.2 x 15.2 x .16 cm (6" x 6" x .063") BSC/Al face sheets bonded (each would yield 4 fully trimmed 5.1 x 5.1 cm (2" x 2") test specimens) to both sides of 2.54 cm (1") deep titanium honeycomb were brazed at target temperatures ranging from 855 K (1080^{o}F) to 878 K (1120^{o}F) for nominal 5 minute dwell times. The dwell times were short since time to reach the target temperature was appreciably longer for these larger mass samples. Temperature control proved difficult in these samples and target temperatures were overrun in all but the low-temperature cases. Resulting braze temperatures were 850 K (1070^{o}F), 855 K (1080^{o}F), 861 K (1090^{o}F), 875 K (1115^{o}F), 883 K (1130^{o}F), and 894 K (1150^{o}F). The joint was prepared using .25 mm (0.010") thick 718 braze foil on each interface and special tooling was devised to control pressure levels at the joint when the thin wall retort was evacuated.

All of the resultant joints appeared to be brazed however the joints produced at the lower temperatures 855 K (1080^{o}F) had negligible flow and did not produce the desired fillets around the honeycomb cells. At the higher temperatures, good braze flow and filleting was evident, but excessive matrix flow occurred causing surface damage to the composite. In addition, penetration of the composite surface by the honeycomb cells resulted in contact with the fibers and varying degrees of fiber breakage. The technique for

TABLE III

STRENGTH DATA FROM DOUBLE OVERLAP
SPECIMENS - TYPE II

BRAZE CYCLE		SHEAR STRESS, MPa (ksi)				FAILURE
Temp. ^{o}K (^{o}F)	Time (Min.)	Room Temp. Aver. data	422 K (300^{o}F)	505 K (450^{o}F)	589 K (600^{o}F)	Type
861/872 (1090/1110)	5	30 (4.3)	40 (5.7)	26 (3.8)	16 (2.4)	Jig moved
866/877 (1100/1120)	10	36 (5.3)	7 (1.2)	9 (1.4)	8 (1.2)	Contamined joint
855/866 (1080/1100)	10	94 (13.6)	82 (11.9)	60 (8.9)	42 (6.1)	
861/864 (1090/1095)	7	76 (10.9)	60 (8.9)	26 (3.8)	26 (3.8)	
861/864 (1090/1095)	7	74 (10.7)	91 (13.2)	61 (9.0)	32 (4.6)	Composite failed
858/861 (1085/1090)	5	43 (6.3)	------	31 (4.5)	17 (2.6)	Composite failed
847/855 (1065/1080)	5	25 (3.6)	------	------	------	No braze, too cool
852/855 (1075/1080)	5	67 (9.7)	63 (9.1)	------	------	Uneven braze
855/861 (1080/1090)	30*	111 (16.1)	------	56 (8.1)	59 (8.6)	@ 589 K composite failed
866/883 (1100/1130)	10	99 (14.8)	------	78 (11.3)	36 (5.2)	Excess braze flow
844/866 (1060/1100)	5	low	------	41 (5.9)	4 (.5)	Incomplete braze

* Rebuilt furnace and larger retort load caused longer time to stabilize braze temperature.

controlling the composite to honeycomb interface needs improvement to prevent this damaging mechanical interaction. Also, more precise temperature control is necessary to assure a brazing temperature of 866 K $\pm$ 5 K (1100°F $\pm$ 10°F). This temperature is sufficient to provide good bonding and filleting without appreciable damage to the composite surface. Joint strengths for these samples were 20.7 - 34.5 MPa (3000 - 5000 psi) but further improvement in technique should yield higher strength. In all cases, composite degradation was evident.

Delivered Items

A total of 175 overlap tensile braze specimens of the three types were fabricated on this program. Of these, 75 specimens were delivered to NASA, Langley for evaluation and the remainder evaluated by DWA. In addition, 24 honeycomb sandwich specimens were produced, and 20 of these were delivered to NASA for evaluations.

Late in the program, additional double overlap tensile specimens, type II, were also delivered to NASA. These specimens utilized titanium foil cladding on the composite to prevent braze diffusion into the composite. Results from these specimens were not available in time to include in this report, but all braze joints appeared sound.

DISCUSSION OF RESULTS

Brazed Joints

A primary objective of the program was to develop effective, practical procedures and processing parameters to achieve sound braze joints between BSC/Al composite and conventional titanium sheet and honeycomb and to establish expected joint strength levels. Further, it was hoped to be able to demonstrate this capability using welded steel vacuum retorts and conventional roughing pump vacuum techniques. The major constraint in this endeavor was to achieve good joints without excessive composite degradation which, in essence, dictated low temperatures and short heat cycle times.

Throughout the course of the program it became apparent that excellent braze joints could be achieved under the environment and process conditions utilized in this effort. In fact, it was established that joint strengths as good as or better than those achieved under high vacuum brazing furnace conditions could be attained (i.e. 117 MPa (17 ksi) when basically all of the required conditions were met. It is clear, however, that all required conditions were not met on a consistent basis throughout the program as demonstrated by the wide scatter in the data. Nevertheless, it is felt that these criteria can now be met on a reasonably consistent basis such that repeatably high strength 97 MPa (14 ksi) to 124 MPa (18 ksi) and complete braze joints can be produced on a regular basis. Table IV summarizes the conditions which appear to be required to produce good braze joints.

The temperature and time variables did not present a clear trend on joiht efficiency during the program since variations in jigging effectiveness and environmental control tend to mask or over power the parameter effects. Neverthe-

TABLE IV

BORSIC/ALUMINUM BRAZING CRITERIA

SHEET PREPARATION

Part surfaces chemically cleaned and abraded.

Contact surfaces must be flat.

JIGGING

Mating parts packaged to permit full vacuum induced pressure uniformity across joint area.

Parts arranged to avoid bending in joint area.

Separator sheets used to avoid bonding in other than joint areas.

Packaged to maintain alignment.

ENVIRONMENT

Maintain pressure below 25μ.

Higher pressures allowable if entire part is enclosed in Ti foil wrap to getter O_2 and prevent back leakage.

PARAMETERS

Temperature must be 855 K (1080°F) under vacuum or lower pressure. At higher pressure, lower temperature works.

Time - between 10 and 30 minutes.

Pressure: For overlap specimens just vacuum pressure will work but higher pressure permits lower temp/shorter time.

For honeycomb core sandwich specimens less than vacuum pressure at slightly higher temps. required to avoid core edges damaging surface fibers.

less, it was clear that the threshhold temperature for good bonding under vacuum pressure is at least 855 K (1080°F) and the degree of braze flow and wetting tends to increase with temperature. Generally longer times are needed at the lower temperatures. As stated earlier, higher than 1 atmosphere pressure offers progressive improvements and permits even lower temperature bonding, assuming joint contamination is prevented.

Generally, premature joint failures occurred for a number of reasons and this must be accounted for in evaluating the results. Premature failures occurred under the following circumstances:

1. Joint contaminated - partially or completely.
2. Joint misaligned so joint thickness not uniform.
3. Composite broke first - degraded.
4. Composite surface layer sheared off due to very high joint strength or less than optimum composite metal-fiber or metal-metal bond.
5. Too much braze flow out resulting in too thin a joint.

In view of these circumstances, it must be assumed that the braze joint (or sound portion there of) was very good in a large number of cases but failure either did not occur in the braze joint or a much reduced joint area carried the entire load. Consequently, it is reasonably assumed that joint strengths of the order of 117 MPa (17 ksi) are achievable over a range of parameters (assuming the other major contributing factors are under control) and that other criteria, such as composite degradation, becomes the limiting factor.

Fig. 5 clearly indicates the potential for not only achieving high joint strengths but maintaining reasonable strength levels to joint test temperatures of 589 K (600°F).

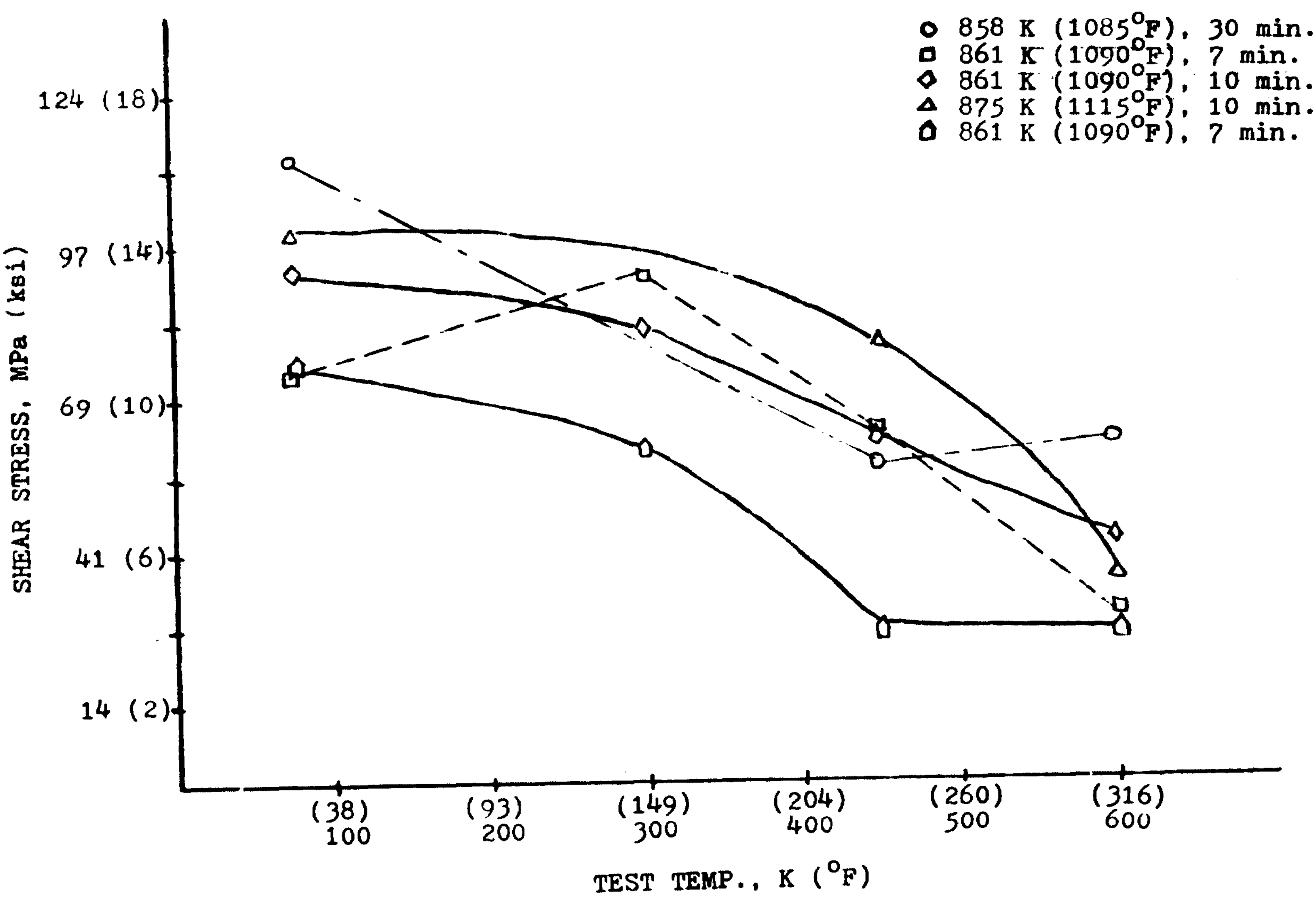


Figure 5. EFFECT OF TEST TEMPERATURE ON BRAZE JOINT STRENGTH
(Double Overlap Type II Specimens)

Note that in all the high strength cases, failure occurred in the composite rather than in the brazed joint which leads to the assumption that somewhat higher actual joint strengths are probable. The premature failures in the composite point up the real problem - composite degradation resulting from the brazing process used.

Composite Degradation

It was hoped at the onset of the program that satisfactory braze cycles and procedures could be found which would permit a sound braze joint with little or no composite degradation. In fact, considerable encouragement was found to support this goal early in the program based on leached fiber tests which showed degradation, but not to an extent which would seriously compromise composite performance; [i.e. 2967 MPa (430 ksi) bend stress]. However, as the effort progressed and braze "joint" failures began occurring in the composite rather than the braze joint it was apparent that composite degradation was occurring to a much greater extent than had been suspected. The failure loads, translated to effective composite failure stresses, fell in the 552-828 PMa (80-120 ksi) range for the composite which represents excessive degradation. This observation conflicted strongly with leached fiber data and thus cast new doubt on the validity of leached fiber properties as a measure of Borsic/Aluminum composite performance.

It had been assumed that leached fiber properties were reasonably representative of the fiber strength in the composite and would translate to composite properties. This is somewhat true of boron, but does not seem to apply to Borsic to the same degree. Apparently leaching restores most of the original Borsic strength by minimizing the effects of point defect strength and thus inhibits crack propagation.

When boron degrades, it degrades all over and there is no doubt. Apparently when Borsic degrades - it is local degradation at flaws or thin spots in the coating and thus can be more easily masked when fibers are etched. This is because the brittle reaction area is; a) localized and small, and b) weakened by leaching, and thus can't build enough energy to propagate a crack when it breaks. However, when intact within the composite, it does in fact act as a stress riser and initiates failure at greatly reduced strain levels.

It was also observed that considerable degradation seemed to occur in specimens having aluminum diffusion barriers as well as in standard specimens. Evidently the potential beneficial effects of thicker interface layers of either 6061 Al or 1100 Al were masked by other factors contributing to composite degradation, and thus no reasonable conclusions can be reached as to the effectiveness of these types of diffusion inhibitors. However, when data become available for titanium clad composites brazed to titanium, the braze diffusion question, as to its contribution to composite degradation, can be answered with some confidence.

CONCLUDING REMARKS

The results of this program demonstrate that high strength braze joints are attainable using roughing pump vacuum levels on a seam welded retort, however manufacturing problems were also encountered which affect joint uniformity, reproducibility and composite integrity.

1. Manufacturing Problems

   - Jigging is a problem in consistently obtaining uniform joints.
   - Joint cleanliness in the vacuum retort must be insured.
   - The braze cycle must be kept as short as possible to minimize composite degradation.

2. Brazed Joint Evaluations

   - Brazed overlap tensile joints with strength exceeding 117 MPa (17,000 psi) are attainable using roughing pump vacuum levels.
   - Braze cycle time/temperature parameters required to achieve strong braze joints caused noticeable degradation of the BSC/Al composite.
   - Effective braze joints require brazing temperatures in excess of $855^{\circ}K$ ($1080^{\circ}F$).
   - Brazing of H/C core to composite face sheets must limit the applied pressure to avoid core edges cutting through the surface layer of aluminum and BSC fibers.
   - Leached fiber tests did not indicate the degree of degradation experienced during typical braze cycles.

RECOMMENDATIONS

Based on the results of this program the following recommendations are made:

1. Identify the precise mechanisms of composite degradation versus time and temperature.
   - thermal cycle effects
   - braze diffusion effects
   - matrix alloy effects - (6061 versus 1100)
   - initial consolidation effects.
2. Evaluate brazing pressure versus temperature.
   - reduce time and temperature to minimum levels
   - higher pressure to reduce temperature (promotes lower temperature braze flow)
   - improves contact area and provides better, more complete and uniform joint.
3. Investigate potential of added metal/filament interface protection.
   - increases thermal tolerance
   - essentially "heals" weak spots in SiC coating.
4. Utilize titanium or stainless steel cladding to prevent mechanical damage in the honeycomb sandwich/interface between composite and honeycomb cell edges.
5. Investigate lower temperature braze concepts.

REFERENCE

Klein, M. J., et al., "Effects of Interfaces in Metal Matrix Composites on Mechanical Properties", Technical Report AFML-TR-72-226, Air Force Contract F 33615-70-C-1814 (Nov., 1972).